

THE ROLE OF WATER TEMPERATURE
IN BRADYCARDIA DURING FACIAL IMMERSION

J. Corriol and J.J. Rohner

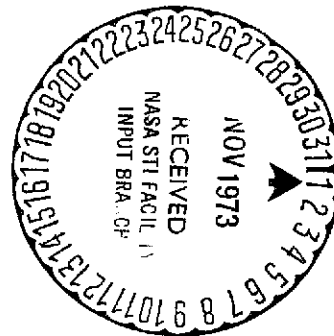
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16. Abstract The authors investigate the role of variations in water temperature upon bradycardia, or stimulus-induced cardiac deceleration. This phenomenon occurs as a reflex when the human face is immersed in water. Using twelve test subjects, the authors carry out facial immersions at various water temperatures, accompanied by accurate electrocardiographic measurement. Through statistical analysis, the effect of water temperature variations upon the bradycardia reflex is demonstrated. The nature of the cutaneous receptors involved in the reflex is also discussed.			
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IN BRADYCARDIA DURING FACIAL IMMERSION

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Introduction and Goals

In recent articles [4,6] we have shown that bradycardia occur- /265*
ing during non-scuba underwater diving includes at least two com-
ponents:

- One is related to the suspension of respiration; this
is more significant with trained divers.
- The other is related to immersion of the face: this depends
on the excitation of facial receptors by contact with water.
Training does not alter this factor which seems to con-
stitute the vestige of an ancestral adaptive reflex, much
studied in the case of diving animals [2,13]. But the nature
of the reflexogenic stimulus producing cardiomoderation
during facial immersion is still unknown. Is it simply a
matter of water contact on the cutaneous facial receptors?
Or is the temperature of the water bath a factor? Few
authors seem to have dealt with this aspect of the problem,
with the exception of Whayne and Killip [16] who point out /266
a more distinct bradycardia during facial immersion without
holding the breath when the water is cold. To answer these
questions, we have again taken up the systematic study of

*Numbers in the right-hand margin indicate pagination in the
foreign text.

bradycardia in facial immersion without holding the breath, investigating the action of variations in water temperature in the zone extending from 0° to 40° C.

Techniques

The experimentation was carried out on 12 male adults, not specially trained in diving, of ages equally distributed between 30 and 47 years. Each subject, placed supine on the stomach on an air mattress, on command plunges his head into a basin of water, so that the face is immersed up to the beginnings of the hair line on the forehead and up to the base of the ears. During the immersion, he breathes ambient air by means of a standard tube. The water temperature is regulated by the addition of ice (0°), cold water (5° to 25°) or by the action of a thermostat (above 25°); a circulation pump maintains a constant current in the bath. Room temperature during these experiments is around 25°C.

Immersion of the face in very cold water (0° and 5°C) is painful; certain subjects tolerate the test badly, shorten it or refuse to begin it again. For this reason, in a second series of experiments we exercised the same experimental technique on the same subjects wearing an underwater diving mask which covered the nose, the eyes and the lower third of the forehead; by this means the painful effects are greatly reduced or eliminated.

Measurement of cardiac rate is carried out by ten-second increments on the electro-cardiographic record. The results are expressed in percentages of initial cardiac rate (before the immersion test); this is indispensable in order to compare individuals whose at-rest cardiac rates are quite different [4].

The subjects underwent the test several times at the temperatures studied; each point on the graph curves represents the

averages of at least three tests carried out by the 12 individuals studied.

Results

Study of the raw results shows a great individual dispersion; roughly, one can class the results in two groups:

- In the first group we shall place the subjects who react to facial immersion with a slight bradycardia;
- The second group includes those who react with an intense bradycardia; their cardiac rates in cold water (0°) may fall to a third of their initial rates; this cardio-moderation often produces extrasystoles.¹ /267

Individual variations are very significant, and for this reason a statistical study was required; the results are reported in Fig. 1, which shows the time-span evolution of cardiac rates expressed in percentage of initial rates, during immersion of the face in water baths at predetermined temperatures ($0, 5, 10, 15, 20, 30$ and 40° C).

One can see, first of all, that after the 40th second, the curves obtained assume regular intervals; the most intense bradycardias are obtained with the coldest baths. There is no discontinuity in the curves, and the curve representing the action of a bath at a given temperature is situated between the curves corresponding to temperatures immediately lower or higher.

For temperatures equal to or above 20° C, the bradycardia attains its maximum value rather rapidly - in about 20 seconds.

¹The electrocardiographic anomalies will be the object of further study.

On the other hand, for the coldest temperatures, the bradycardia takes proportionately more time to establish itself as the temperature of the bath is lower; thus, at 0 to 5°, it takes around one minute for the bradycardia to attain its maximum value.

In the initial period of facial immersion, for moderate water temperatures in the bath, the bradycardia begins after the 10th second; but at extreme temperatures (0, 5, and 40°), where the stimulus represents a painful aggression, one notes a temporary tachycardia at the 10th second, which disappears at the 20th second, when the pain becomes less intense. In the same manner, after the 60th second during immersions of the face in very cold water (0 and 5° C), the bradycardia clearly diminishes. This corresponds to a period when the subject fights to maintain his face in the water, despite the painful sensations he experiences around the eyes and the second frontal-maxillary sinuses.

If the subjects wear an underwater diving mask covering the eyes and the nose, these painful sensations are lessened and better tolerated. In this case the bradycardia is no less significant in its fully established phase (after the 60th second), but the initial tachycardia is slight or absent, and the bradycardia remains stable once established, since the subjects are no longer fighting against the pain caused by the cold (Fig. 2).

Another type of graphic representation allows a clear depiction of the effect of temperature on bradycardia; in Figure 3, we have represented the cardiac rate in percentage of at-rest rate, as a function of the water bath temperature at the 60th second of facial immersion. One notes that, in the vicinity of 26.8 the temperatures deemed "pleasant" by the subjects, temperatures whose thermal stimulus is "negligible" (20 to 30° C), bradycardia is very slight; but at cold temperatures, the cardiac deceleration

is proportionately more pronounced as the water in the bath is colder.

The curves which one can trace between the 40th and 90th seconds of facial immersion may almost be superimposed on the curves of Figure 3.

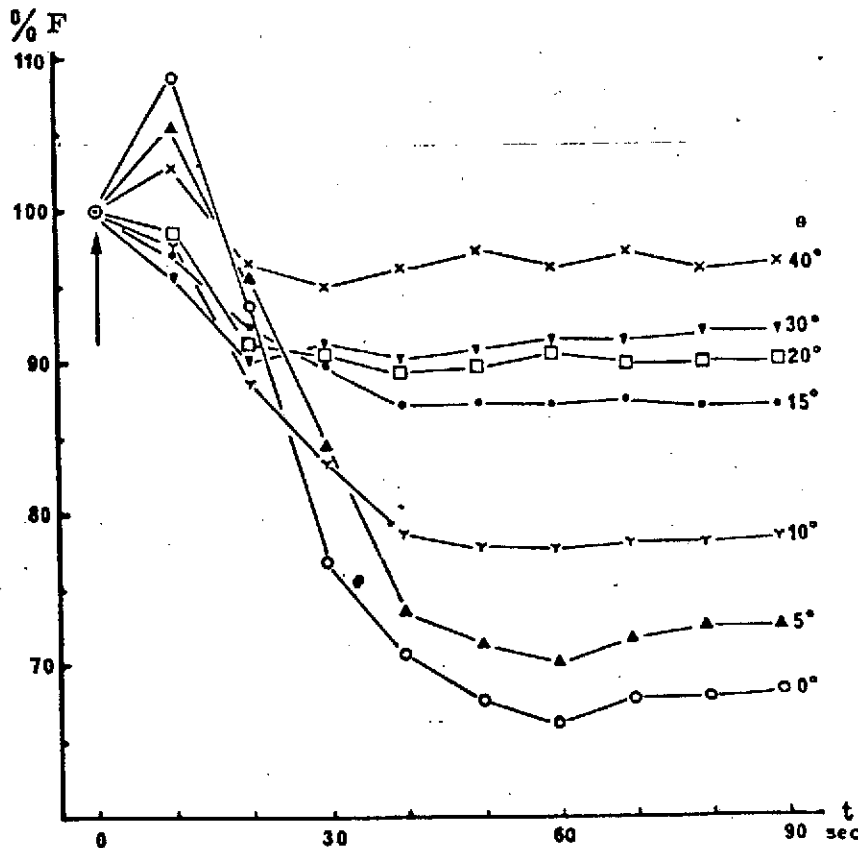


Figure 1. Immersion of the face in a water bath at various temperatures (0° , 5° , 10° , 20° , 30° , 40°). The curves express the evolution of cardiac rate (in percentages of at-rest rate) as a function of time for each temperature. Each point on the curve represents the average of at least three tests carried out by each of the twelve subjects studied. The subjects were breathing free air through a tube and wore no mask.

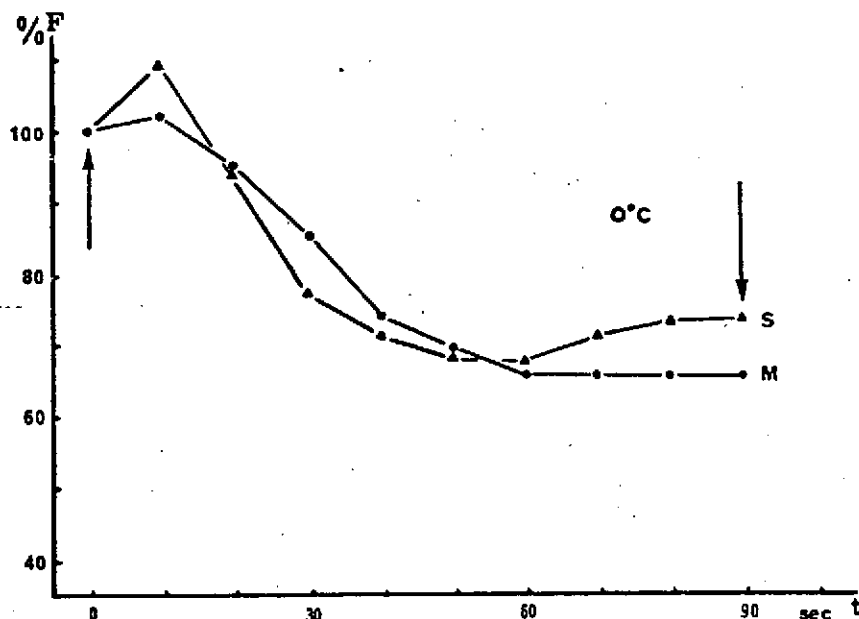


Figure 2. Effect of wearing a diving mask during immersion of the face in water at 0° C. The curves represent the results while wearing the mask (curve M) and when the mask was not worn (curve S). The two curves are for the same twelve subjects having performed three tests each, with and without mask.

Discussion

In all the experiments, we interrupted the facial immersion at the 90th second; in fact, after the 60th second, the curves expressing cardiac rate as a function of time may be thought of as becoming nearly horizontal; it is useless, therefore, to pursue the immersion beyond a minute and a half.

Statistical Study

Is the statistical technique used valid? In point of fact, we carried out the study of cardiac rates by 10-second increments;

it is difficult to work with shorter increments because of the frequent irregularity of heartbeats at low temperatures. However, we have verified in a certain number of cases which might lend themselves to this criticism, that the method of movable averages (with 10-second "doors", scaled down from two in two seconds) furnishes identical results to those obtained by the method of initially fixed averages [4].

The margins of error of the average at 0.05 are reasonably high; they attain their minimum value ($\pm 2\%$ 100) at the temperature 20°C ; their values increased at extreme temperatures (Fig. 3).

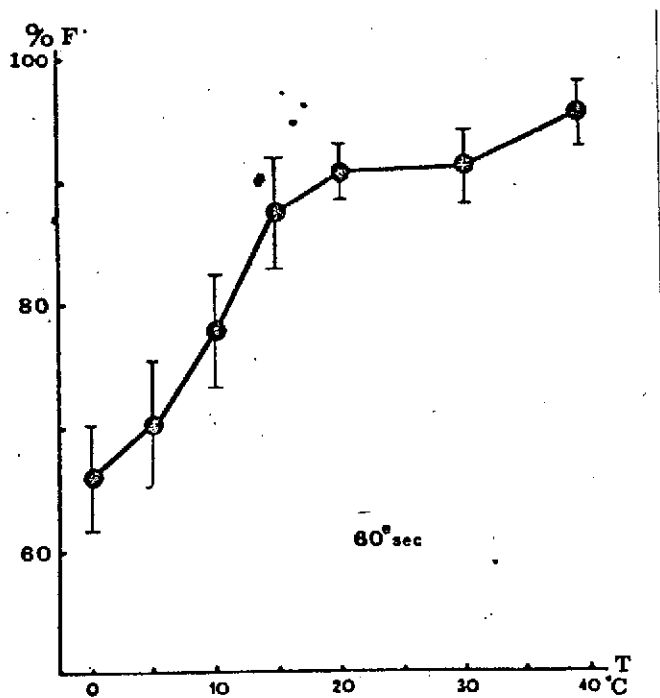


Figure 3. Curve representing in the fully established phase (60th second), the intensity of facial immersion bradycardia (in percentages of at-rest cardiac rate) as a function of water bath temperature; average of twelve subjects having performed three tests each at each temperature. Margin of error of the average, 0.05, are shown.

This observation simply translates the fact, apparent from simple observation of the individual figures, that changes in cardiac rate are quite variable from one subject to another for the same bath temperature; some show a slight cardiac retardation, even during immersion in water at 0° , while with others the /271 cardiac rate may fall to a third of the initial value. Moreover, from one day to another, even from one hour to another, the bradycardia obtained in a given subject under identical experimental conditions may vary from one to two times; we have no explanation to take this phenomenon into account. By the same token, with certain persons studied several times a year for three years, immersion bradycardia became progressively attenuated, while it became more pronounced in others.

In spite of these individual differences which raise the margin of error of the average to 0.05, are the results obtained meaningful? Examination of Fig. 4 permits an affirmative answer to this question. One can see that, from the 40th to the 90th second following immersion of the face, the points obtained for each water temperature are grouped and present a spread of only /272 a few percentage points. This allows us to affirm the reproductibility of the phenomenon in the group of subjects considered, without having recourse to variance analysis. Moreover, given the speed "on the flat" of the curves representing the percentage of cardiac rates at each temperature beyond the 40th second (Fig. 1), it may be admitted that the number of tests can be considered six times as large; the new margin of error will therefore be notably smaller, since it will be divided by $\sqrt{6}$ (Fig. 4). In fact, two successive points on a curve of Fig. 1, for a given individual, are not independent; it ensues that the real margin of error is greater than that indicated on Fig. 4 and less than that indicated on Fig. 3.

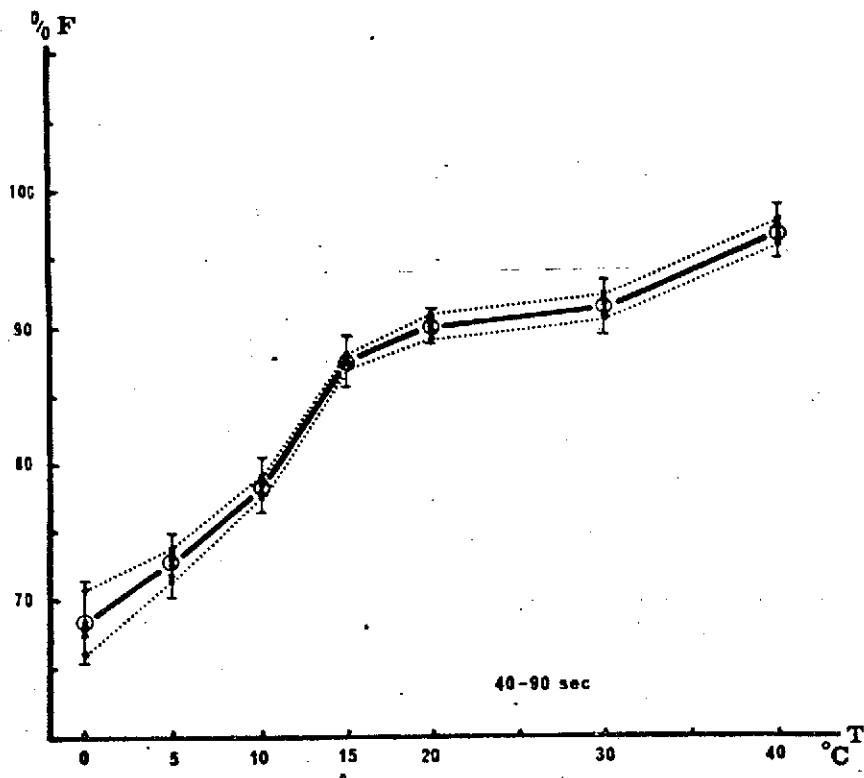


Figure 4. Frequency of cardiac rate (in percentages of at-rest cardiac rate) as a function of water temperature; this curve results from the summation of results obtained between the 40th and 90th second of facial immersion; the new margins of error of the average, 0.05, are shown.

Effect of Cold and Heat

The curve of Fig. 4 representing the fully established period (after the 40th second of facial immersion), the percentage of cardiac rate being a function of water temperature, may be roughly divided into three segments:

- From 0 to around 15° C, the curve approaches a straight line; bradycardia becomes proportionately more intense as water

temperature becomes colder; the slope of the curve borders on 2.5% for every degree centigrade;

- From 20 to 30° C, the curve presents a nearly horizontal plateau; this interval corresponds to temperatures judged "pleasant" or "temperate" by the subjects (neither hot nor cold); the thermal stimulus is then negligible and seems to have little effect on cardiac rates; only the aquatic stimulus would be at work here, caused by the contact of water with the face, independently of the water temperature which is no longer noticed;
- Above 30° C the subjects react with a very slight bradycardia; they consider the water "hot" and present a distinct facial vasodilation during immersion. It is probable, but not demonstrated experimentally, that two phenomena are then superimposed: an immersion bradycardia of little intensity, and a tachycardia, probably of traumatic origin, which finally dominates.

Confrontation with Other Givens

It is difficult to compare these results with others, because no author seems to have made a systematic study of the effect of water temperature on bradycardia of facial immersion. However, Graig [7] and Olsen et al [11] have noted, during total immersion holding the breath, that bradycardia are more intense if the water is colder.

Wells, quoted by Tuttle and Templin [15] also notes, but under quite different conditions, a cardio-acceleration in a hot bath, as well as a bradycardia in a cold bath. The results of Keatinge /273 and Evans [10], obtained under conditions quite different from our own, cannot serve as a point of comparison.

On the other hand, Whayne and Killip note, in water at 0° C, a bradycardia at 65% of initial cardiac rate, a figure close to ours (66%). But at 25°, these authors mention a cardiac deceleration of 80% of the initial value, a figure much farther from ours (about 90%), without its being possible to explain the discrepancy.

Nature of the Receptors Brought into Play

It seems likely that three types of cutaneous receptors are involved [13]:

- Thermal receptors sensitive to cold, which, it is known, are particularly abundant around the lips and the perioral region; they are two or three times less numerous on the rest of the face; this explains why the wearing of a mask does not diminish the intensity of the bradycardia;
- Thermal receptors sensitive to heat, few in number and presenting a high threshold, which accounts for the slight intensity of bradycardia obtained while plunging the face into water at 40° C;
- Hypothetical receptors sensitive to contact with water; these would perhaps be the mechano-receptors described by certain authors; they are perhaps intermingled with cold-sensitive receptors.

Conclusions

In a subject breathing through a tube, immersion of the face in water, at temperatures ranging from 0° to 40° C, produces a cardiac deceleration; statistical study of the results shows that:

1. In the zone 0 to around 20° C one obtains a bradycardia proportionately more intense as the water is colder; at

- C, cardiac rate falls to about 72% of the initial value;
2. In the temperate, or thermally comfortable zone, bradycardia is slight (90% of initial cardiac rate);
 3. In the hot zone, bradycardia is very slight (a few percent);
 4. Bradycardia occurs proportionately slower as water temperature is lower, and cardiac deceleration is more distinct; after the 60th second, the cardiac rate remains stable at its new value, depending on water temperature, provided that the immersion is not painful, as is the case in very cold water;
 5. Initial tachycardia noted at extreme temperatures is doubtless of traumatic origin; it is attenuated or disappears entirely with the wearing of a diving mask.

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